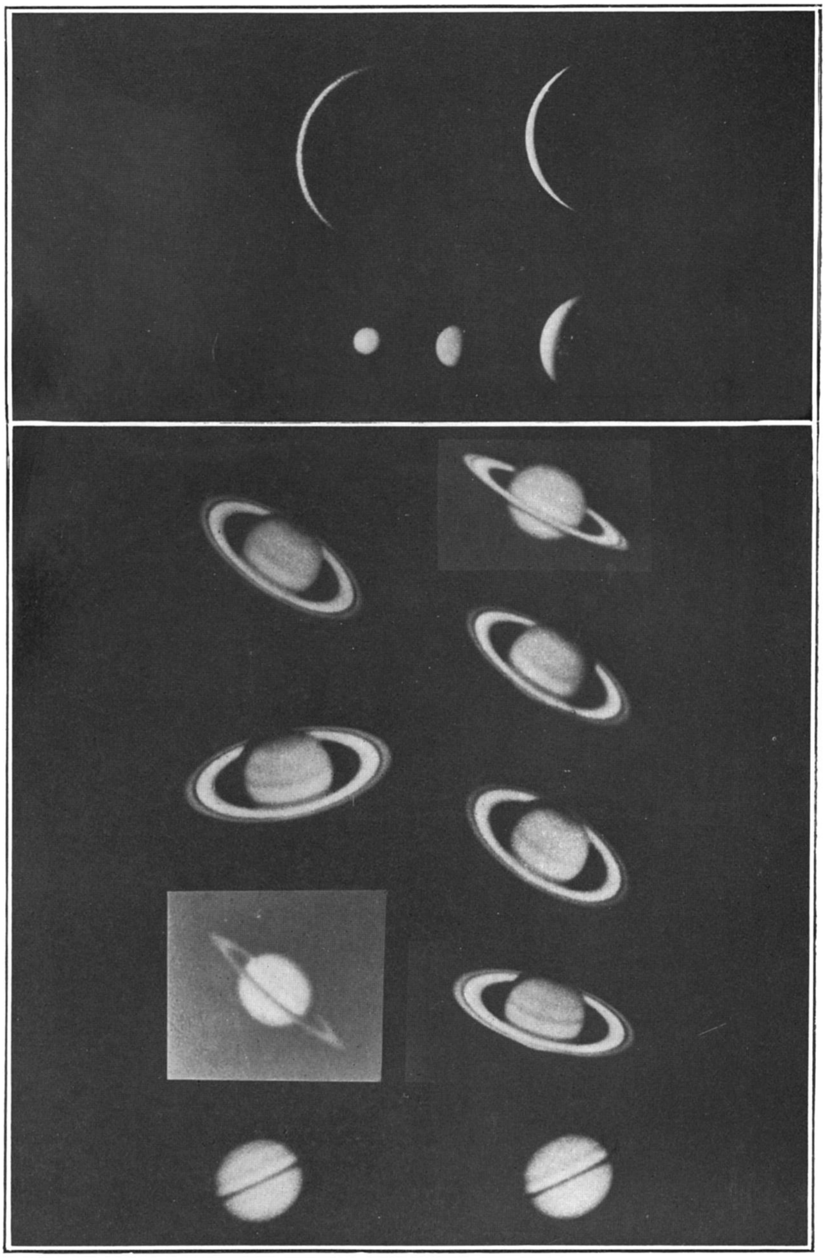

PLATE I
Photographs of *Venus* and *Saturn*
—Lowell Observatory

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PHOTOGRAPHING THE PLANETS WITH ESPECIAL REFERENCE TO MARS[1]

By E. C. Slipher

During the last quarter of a century the application of photography to researches in astronomy, and in other sciences as well, has brought numerous important advances. Thru its use in astronomy we have confirmed or refuted old theories and created new scientific belief. Many of the old ideas that were derived from visual observations thru the telescope have later proved to be wrong, when the better means of securing data by photography came to be employed. Therefore, at present most astronomical observations are either secured photographically or are corroborated, if possible, by the photograph.

In 1874 Dr. H. W. Vogel of Berlin discovered that the silver salts of the photographic emulsions, which are ordinarily sensitive to blue light only, could be rendered sensitive also to light of longer wave-length toward the red end of the spectrum by the application to the emulsion of various dyestuffs. With this advent of the (so-called) isochromatic plate and its accompanying color-filter it became easily possible to employ the visual refracting telescope as a photographic camera. This finally led to the study of the surface features of the planets thru the photographic plate.

The special method and its development by which successful, highly magnified photographs of the planets have been obtained are chiefly due to experiments and investigations carried on at the Lowell Observatory since 1901. And as its successful development was mainly due to a determined effort to photograph the so-called canals of *Mars*, special reference will be made here to the results obtained by its application to that planet. However, its application to *Venus*, *Jupiter*, and *Saturn* has met with similar success and photographs of these planets will also be discussed.

[1]A lecture delivered in Native Sons Hall, San Francisco, under the auspices of the Astronomical Society of the Pacific, on January 28, 1921.

Several years have been spent in designing and perfecting instrumental means with which to obtain photographs of the planets just as they appear in a large telescope. The first attempts to photograph the finer markings on *Mars*, in this manner, were by Mr. A. E. Douglass at Flagstaff in 1901, but it was not until 1905, with improved methods by Mr. C. O. Lampland, that the first successful photographic record of the canals were obtained by him. Increase in quality of delineation in the photographs followed various subsequent improvements. I shall describe briefly how this was accomplished.

First of all, the images of the various planets at the principal focus of the telescope objective are too small to show planetary detail on a photographic plate sufficiently well to be of the most practical value for subsequent study. Therefore, it is necessary that this image be amplified, and to do this a second lens is inserted in the beam of light at a proper place near the focus of the big object glass. This amplifying lens does for the photographic plate, under proper manipulation, just what the ordinary eye-piece lens on the telescope does for the visual observer. The purpose and behavior of the two are quite similar. But a special lens is provided in order to secure the most perfect image of the planet when the lens is combined with the telescope objective, in fact several have been constructed after taking into account every detail of the telescope objective and those we now use are highly efficient. This amplifying lens allows, by adjustment in position with respect to the focal point of the objective, any size of image desired. But still another difficulty stands in the way of success.

This is the chromatism of the telescope; the inability of the visual refracting telescope objective to bring light of different wave-lengths to the same focal point. In a visual telescope the particular wave-lengths to which the eye is most sensitive are the only ones that are sharply focused in the telescopic image. The unfocused light, which the optician disregards in making a visual objective, however, does not interfere with eye observations, but with the photograph it proves ruinous because the rays that have been let go astray of the sharply focused image are unfortunately the very ones to which the photographic emulsion is most sensitive. To rid the image of this worse than useless stray light and secure unity of focus is necessary to photographic definition.

This is done by filtering the light thru a scientifically constructed ray-filter. These filters can be prepared so as to transmit light of any wave-length desired, but in this case they must be adapted first to the color curve of the telescope lens so that only the light that the optician corrected the telescope object glass for, is admitted to the sensitive plate. The wave-length of this light for the Lowell 24-inch refractor is about $\lambda 5600$, this being the mid-point of the flattest part of focal color curve of the objective. The properties of such filters have been determined and they have been provided for the 24-inch telescope after taking into account all the essential factors involved. In order to obtain the nearest optical perfection in their practical application, various ones have been made from time to time for the observatory, chiefly by Mr. R. James Wallace. These have slightly different light transmissions, the idea being that with various plates some improvement might be encountered by using light from slightly different regions of the spectrum. All these are orange-yellow filters and transmit the light from wave-length 4600, or with some of them 5000 and greater; that is, the yellow, orange and red rays. These rays, except the red, have practically the same focal point in the Lowell telescope which amounts to saying that the light has been rendered mono-chromatic or that unity of focus has been secured. True mono-chromatism is not realized, and if it were the light would be too feeble to be effective, yet, the result is practically so, because other factors of more moment, such as seeing, affect the delineation far more.

Next we must find a photographic emulsion that is sensitive to orange light, as ordinary plates are strikingly insensitive to this color of light. Therefore plates of special sensitiveness are necessary to meet such a requirement. Ordinary plates can be made sensitive to orange light by treating them properly in a bath of certain dyes. Many of the plate manufacturers by similar processes have provided such plates under various trade names, such as the Cramer Isochromatic, Trichromatic, and Isoprocess plates; the Ilford Panchromatic plates; the Eastman Orthochromatic and Panchromatic plates; and various other special plates. All such plates which gave promise of success have been tested in connection with this work but only two have been found well suited to it. In fact our investigations along this line have shown that the Cramer Isochromatic emulsion is by far the best suited to the work, but even these, in spite of their good qualities, leave much to be desired.

While the sensitivity curve of these plates corresponds to the color curve of the telescope objective, having a second, high maximum of sensitiveness at λ5600, as they do, yet their lack of speed and the granularity of the silver emulsion are serious obstacles. These qualities are very important in photographing such fine detail as we are concerned with in this problem.

In consequence of these defects considerable experimenting has been done in sensitizing our own plates for photographing in the visual rays. And while this, in the hands of Dr. V. M. Slipher, has been perfected and has led to advances in spectrum analysis, no decided advance was made in the direct photographs of the planets. The chief fault with such plates is that their sensitivity extends too far into the red end of the spectrum, and the absence of any high maximum in the longer wave-lengths, which results in poor definition in the photograph, due to the greater extent of the objective color curve embraced. Obviously the ideal plate for photographing with a visual refracting telescope should be highly sensitive to a narrow range of the visual spectrum. The Cramer "Isochromatic Instantaneous" and "Isochromatic Medium" possess these properties to a degree, being insensitive to the out-of-focus red rays, having a relatively high, narrow maximum sensitiveness in the yellow at λ5600 which is coincident with the flat portion of the color curve of the objective.

This brings us to the next step, that of focusing the camera. This is generally done by means of star trails and must be adjusted with extreme care. Even when the equivalent focal length of the camera system is as great as 180 feet, an error of more than two hundredths of an inch is perceptible. This fact discloses the defining power of the camera system.

Then, in making the exposure, it turns out that even on the fastest photographic plates a time exposure is necessary to get a picture of a planet, the duration of exposure depending chiefly upon the particular planet being photographed, and the scale of the image. In the case of *Venus* the exposure is about one-third second, *Mars* one and one-half to two and one-half seconds, *Jupiter* about five seconds, while in the case of *Saturn* the exposure time ranges from fifteen to thirty-five seconds. Now this relatively brief time of exposure no doubt seems of little importance and it is, if we were concerned in photographing a still object, or one subject to our control, but in the telescopic image we have neither of these. Aside

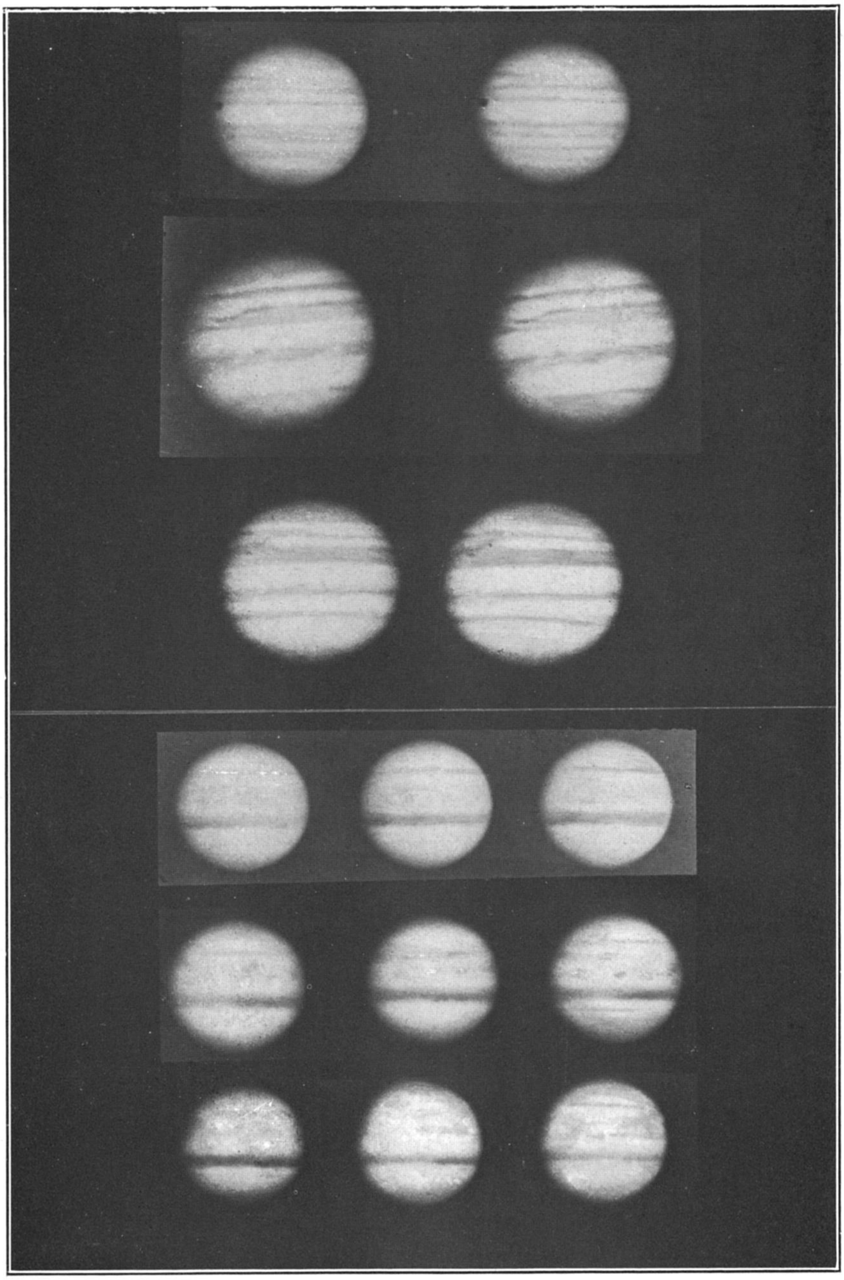

PLATE II
Photographs of *Jupiter*
—Lowell Observatory

from the minor difficulty of guiding the big telescope, our air waves cause a motion of the image which in time exposures obviously causes blurring because it is impossible to move the plate to allow for such rapid oscillations. Thus the resulting image is a poor average picture of the planet during the entire exposure time. Because of variations in seeing, many images are taken on each plate in order to catch the planet, if possible, during the moments of best definition. In fact, the terrestrial atmosphere is the chief obstacle that militates against securing the sharpness of delineation required to register in the photograph the very finest planetary details.

It is evident from these facts, then, that the longer we expose the plate the less detail will be secured. To reduce the time of exposure to its shortest compass is one of the essentials to success, endeavoring thereby to catch the moments of most perfect definition. On the other hand, to shorten the exposure time is to reduce the amount of light that the plate receives, and a modicum of light is necessary to securing a photograph of sufficient density. However, if the size of the image on the plate is reduced there will be a greater concentration of light which, in turn, will permit a shorter exposure to be given, but this can be done within limits only, as the image of the planet must be kept sufficiently large as compared with the granularity of the emulsion to admit of successful scrutiny in its subsequent study. Therefore this question has been settled by a compromise between scale of image and exposure time so that neither shall become a bar to securing the sharpest image of the planet of the largest practical size.

At present the camera system is usually used at an equivalent focal length of about 180 feet. This means that the image of a planet on the plate is magnified about two hundred times. To put this in more familiar terms, the size of the photographic image of *Mars*, taken when it is near the Earth, is from four to six times greater, in surface, than the Moon seen with the unaided eye. The subsequent enlargement that these negatives receive increases their size considerably, but owing to the destructive effect upon fine detail of the relative large silver grains of the photograph, this increase cannot be great or the detail is obliterated. In the case of *Jupiter*, *Saturn* or *Venus* where we are not so much concerned with extremely fine detail the negatives bear much greater enlargement.

This, then, is the method by which large scale photographs of the planets are obtained with the 24-inch Lowell refractor. Since 1905, when the visual method of observing planets was supplemented by

this photographic process, a systematic photographic record of *Mars*, *Jupiter* and *Saturn* has been maintained. Of *Mars* alone these photographs number nearly 100,000. In 1907, while on an expedition sent out by the late Dr. Lowell to observe *Mars* from the arid plateau region of the Chilean Andes, the writer made more than 13,000 negative images of *Mars*. The total number of photographs of the various planets approximates 250,000.

While it is true that, under like conditions, more planetary detail can be observed visually than photographically, yet the photographs are of great value because they furnish a permanent pictorial record of the planet surfaces, with the correct geometrical arrangement of the details and their relative light intensities. Their faithfulness and permanency provide incontestable data for future generations of scientists, and being unmeddled with by man as they are, they constitute a thoroly dependable record for future comparisons. Therefore, facts that so far have failed of detection will undoubtedly emerge from them as the interval of time they cover widens, and comparisons go on.

In discussing the results of the photographs, there is not space here to enumerate the detailed facts brought out by them; therefore brief generalities must suffice. *Jupiter*, due to the great size and brilliancy of its image, lends itself particularly well to photography. Moreover, owing to the rapid transit of the markings across the face of the planet due to the rapid axial rotation, I believe that a better representation of the true relation of the markings is obtained in the photograph than in the best drawings. The accuracy with which the photograph records the belts, cloudlike spots and other details, in their true relative positions and intensities, makes a very valuable register of Jovian *phenomena*.

The original negative images of this planet, taken when near opposition, somewhat exceed one-half inch in diameter. The exposure times range from three to seven seconds.

Photographs taken at different times, but of the same longitude, portray many evident chaotic changes there. They show changes of enormous extent, sometimes in an interval of but a few days. At times, an interval of hours only is sufficient to show change in some markings. The photographs show at a glance the conspicuous belted appearance of the planet and closer scrutiny shows them to be replete with finer detail. The vastness of these changes and the rapidity with which they occur show them to be atmospheric in character.

The photographs of *Mars* made at the Lowell Observatory furnish objective evidence of the truth of the following general statements concerning the planet:

That the polar caps gradually melt in the Martian summer—in case of the south cap, this sometimes proceeds to extinction—and form again in the Martian winter.

That the making cap is of an indefinite contour, of a misty white, merging gradually into the surrounding land.

That the melting cap, on the contrary, is bordered by a dark band which retreats marginal to the cap.

That the surface of the planet is divided into reddish ochre and dark, bluish-green areas, the former being greatly in excess of the latter in extent.

That the bluish-green regions, which were once thought to be oceans, cannot be such because they are shown to be lined by dark markings and spots permanent in position, which could not be the case were they of water.

That the dark markings undergo change, apparently fading in the Martian winter and markedly increasing in intensity in the Martian summer.

That the south polar cap melts to a smaller compass than the northern one.

That frost patches occasionally appear in the Martian autumn, not exactly at the pole but some distance from it equatorward, namely at about latitude 60°.

Also, that these sometimes appear on the sunrise edge of the planet, never to arrive at noonday.

That shortly following the appearance of these, the new misty, winter cap begins to grow.

That the melting cap breaks up in certain places leaving behind some of the glistening white deposit as it retreats. These residue patches slowly contract too, and in a comparatively short time entirely disappear.

That the polar caps are not only much more brilliant than any other part of the planet but that they also shine by a bluer light.

That the light regions of the planet are tinted reddish yellow. The presence of limb light around the margins of the planet, indicating the existence of an atmosphere of comparatively small mass. The existence on the surface of the planet of a network of dark, linear markings—the "canals," and small, dark spots—the "oases."

That these line-like markings are sensibly continuous and uniform thruout.

That at the places where they meet there are small, dark spots.

That the canals have individuality, however, as between themselves, some being much larger and more prominent than others.

That the oases, also, differ in size.

That the canals run from one point to another with regularity, and never stop short of a definite point of destination.

That they intersect one another at all angles; frequently several intersect at one point.

That many instances occur where two intersect and both continue to run precisely on their own straight course. (This is not so with rivers or other natural markings on the Earth's surface.)

That some of the lines lie near together and parallel—the double canals.

That the separations of these differ.

Furthermore, that all the dark markings undergo inherent change. And that these changes are gradual, but marked—suggesting that they are systematic.

That the Martian day is generally quite clear. But that occasional vast clouded areas appear. (Confirming the results of spectrographic investigations on the Martian atmosphere at Flagstaff.)

That these occur in the late summer when the cap has melted to its smallest extent.

That on still rarer occasions atmospheric storms appear on the terminator of the planet as projections.

That clouds appear regularly at the autumn pole of *Mars*, preceding the appearance of the new cap and accompanying its growth. With the approach of Martian spring this misty veil lifts to disclose a hood of glistening white deposit beneath.

Moreover, the majority of the canals that have been observed visually at the Lowell Observatory have been recorded repeatedly on the vast number of photographs made during the past fifteen years.

Finally, that the extensive visual observations made at the Observatory have been confirmed *in toto*, and corroborated in detail, by the photographs.

Thus it will be seen from this recounting that they give faithful support to the truth of the conclusions reached by Lowell concerning the physical conditions existing on *Mars*.

Up to this moment, I have stated, so far as I know, nothing but well authenticated facts about the photographs and the immediate conclusions which they force upon the mind. But, the mind is so constituted that it does not willingly rest in facts and immediate causes, but seeks always after knowledge of the remoter lengths in the chain of causation. Taking the many changes portrayed in the photographs of the different planets, we cannot refrain from asking ourselves how these changes have occurred. And it is interesting to note that in planets, even more so than in people, the facial expression is telltale of life conditions.

That other bodies in the universe besides our little Earth were the abode of life has long been a speculation of mankind, and as in every kind of speculation seemingly impossible of proof, there have been two opinions in the matter. However, we now possess information which warrants, better than ever before, deductions of this nature. But in one short hour for a bird's-eye view of these members of our solar system we cannot recount all we have recently learned of them, and I can only briefly review the evidence bearing on this question of their evolution.

In this discussion we shall first consider *Saturn*. About him we have learned not a little; both as an individual and from a cosmic point of view. Briefly, our knowledge of this planet tells us that the body of the planet is in a molten, plastic state and encompassed by a very dense atmosphere thru which we seldom, if ever, see. While his wonderful ring system causes him to stand unique as a member of the solar system, yet his state of evolution is almost identical with that of the next planet we shall discuss.

Jupiter, the giant of our system, measures 86,000 miles in diameter, with a bulk 1300 times that of the Earth, and a mass 318 times our own. Older probably than any of the planets, he is at the same time, much younger than those known as the terrestrial group. To his great mass is due his youthful state, for mass determines how quickly a planet is to age. For, cosmically, cooling produces age, and cooling proceeds more speedily the smaller the body is; for which reason, *Jupiter*, altho of immense antiquity in time, is of great youthfulness in constitution. Nevertheless, because his birth probably preceded that of any other of the outer planets, he is clearly more evolved than they. In spite of his huge mass, he has so far advanced that his mean density is .31 that of the Earth and considerably exceeds that of any of the outer planets. In this process he

has become very hot, flushing thru the greater part of his cloud envelope a dull red. All our knowledge of this planet bears testimony that the rapid currents in his belts and the violent outbursts we see there are due to an intense internal heat and its effect on the dense vaporous envelope that surrounds the planet, beyond which we seldom, if ever, see. Thus, it is obvious that *Jupiter*, like *Saturn*, has not advanced to the state of evolution consistent with life-supporting conditions.

In the case of *Venus*, from the size and mass and the planet's position with respect to the Sun, we should expect it to be in a state very similar to the Earth. She has a diameter of 7,700 miles and travels in an orbit inside the Earth's, being only two-thirds our distance from the Sun.

It is rather sad paradox that *Venus*, the nearest of all the planets and therefore the most favorably situated for study, should be the one upon which any markings are very hard to see. Only *Neptune* and perhaps *Uranus* are more difficult objects. To detect markings on *Venus*, from which her day may be deduced, requires far greater skill on the part of the observer than is necessary to see the canals on *Mars*. However, several observers have made noteworthy and trustworthy observations of her, among them the noted Italian, Schiaparelli, who first detected the canals on *Mars* and then went on to detect the length of the day of *Venus*. This he found to be 225 of our days, or equal to her period of revolution about the Sun. This result was later confirmed by Lowell and others. Others, however, found evidence that she turned once on her axis in twenty-four hours. But Dr. V. M. Slipher, by spectrographic observations, found no evidence of the shorter rotation period but rather that the time of its daily rotation was long. As only two different periods for its day have been deduced, one of about twenty-four hours and the other 225 days, and as the shorter one has been disproved by the spectrograph, the only alternative left us is that *Venus* rotates in 225 of our days.

This would mean that the planet always presents the same face to the Sun. If this is the case, one-half of the planet is perpetually facing the burning heat of the Sun and the reverse hemisphere forever stands in icy darkness. This condition, if true, has been brought about by the tidal action of the Sun which has rendered her rotation synchronous with her period of revolution.

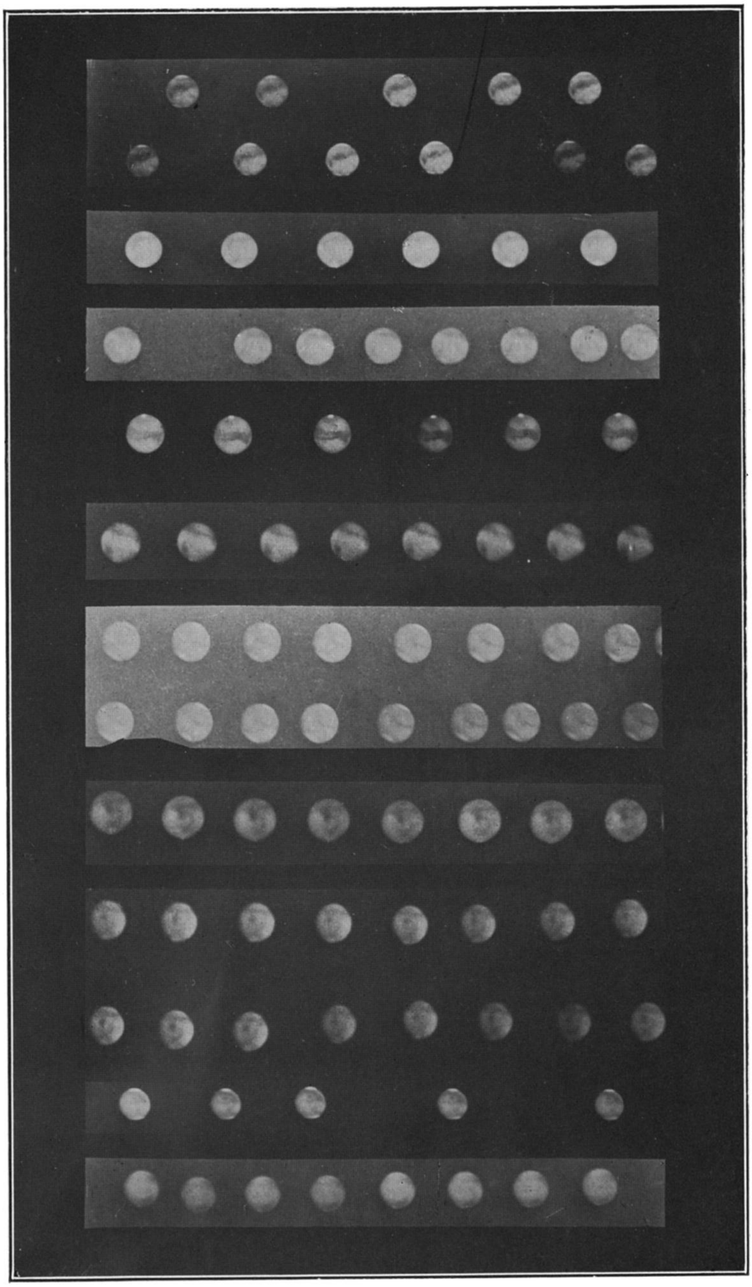

PLATE III
Photographs of *Mars*
—Lowell Observatory

That *Venus* has an atmosphere is certain, but its exact extent and density are still matters of some doubt. The planet's high albedo proves the existence of an atmosphere, and the extension of the cusps beyond a geometric semi-circle of the planet, when seen as a slender crescent at the time of inferior conjunction, is another indication. Dr. H. N. Russell concludes from his investigations of this phase of the planet, that her atmosphere is of small extent and density, not more than one-third that of the Earth's. Further, spectrographic observations at Flagstaff show that if water vapor or oxygen are present in her atmosphere in quantity, they fail to manifest themselves in the planet's spectrum. Hence, we may conclude that researches on *Venus* have brought forth no evidence of life supporting conditions there, or that it may be an abode of life.

Now we are left with the planet *Mars*, only. *Mars* is much farther on than *Jupiter* and our Earth in his planetary life. This, his smaller mass would bring about, if he started at all co-eval, and his face shows every sign of advancing age. And this should be of interest to us, because he must have traveled much the same road that we ourselves are likely to follow. Because of this similarity and in order to give no foundation for the accusation that we are running counter to principles of natural philosophy in this discussion, I shall follow the logical and safe course of reasoning from known analogies on our Earth, supported by our knowledge of terrestrial matters. And in discussing this subject, I place before you the results of my attempts to sift the well established from the hypothetical or doubtful.

First of all, three things are essential to organic life: water, oxygen, and sufficient warmth. It is necessary, then, to prove the existence of these three things on *Mars*. And this brings us to the question, "What is proof?" Proof, except in mathematics, consists in an overwhelming preponderance of probability.

That water vapor and oxygen exist in the atmosphere of *Mars* is of the same order of certainty as that hydrogen and calcium, or what not, exist in the far distant stars. In both cases their existence is necessary to account for lines in their respective spectra. Indeed, the proof of these gases in the stars, tho thoroly convincing, is not so complete or cogent as is the testimony of the existence of water vapor and oxygen on *Mars*.

Water vapor has shown its presence in the Martian atmosphere in spectrograms made at Flagstaff under exceptionally favorable

conditions for its detection. This, linked with the behavior of the polar caps of the planet, their waxing and waning with the seasons there, making their behavior perfectly analogous with our earthly ones, is another proof. The melting cap on the other hand is bordered by a bluish belt which retreats and keeps in contact with the cap. This shows it to be a product of the disintegration of the cap. The fact excludes the possibility of the caps being formed of carbon-dioxide, because that substance, at pressures of one atmosphere or less, such as exist on *Mars*, passes at once from the solid to the gaseous state. We are left, therefore, with the only substance we know of which could give rise to this phenomenon—water. Furthermore, the cloud covered areas shown in the photographs lend their telltale evidence that they, too, are of the same substance as our terrestrial clouds. As carbon dioxide is invisible as a gas, it could not produce this effect. Thus it seems that we can safely accept the existence of water vapor on *Mars*. In fact, if we attempt to explain the various phenomena which are seen there, we are forced to accept this conclusion. The same spectrographic observation that disclosed water vapor on *Mars*, gave proof, likewise, of the existence there of oxygen.

Now we have come to the next point—that of temperature. By theoretical mathematics various mean surface temperatures have been deduced for *Mars*. Dr. Moulten of Chicago, by mathematical deductions based on certain assumptions, arrived at -39 degrees F. as the mean surface temperature of *Mars*, but adds: "The results just obtained can lay no claim to any particular degree of accuracy because of the uncertain hypotheses on which they rest." Dr. Poynting, in England, by similar mathematical reasoning, got a somewhat different result from Moulton, in fact he gives three results based on different hypotheses, but he too concludes with a qualifying statement almost identical with that quoted from Dr. Moulton. However, Dr. Lowell, by like mathematical reasoning, but by the inclusion of additional factors vital to a correct result, got about 48 degrees F. for the mean surface temperature of *Mars*. This result is not far from the mean annual temperature of the Earth, the latter being about 60 degrees F., or 28 degrees above freezing.

But from the Earth we get a criterion of the temperature on *Mars*. Snow melts at 32 F. and therefore, at the poles of *Mars*, when the caps are melting, the temperature must rise to this point at least. We can reason from this, then, that the temperature must

increase very markedly towards the equator of the planet. This, as well as other observed facts, comes out to agree with the temperature deduced by Lowell. The whole aspect of the disk of *Mars* bears out the conclusion that the temperature is not very low. The seasons at which the melting of the polar cap begins, and the time at which it is brought to an end, at what corresponds to about the 20th of August in our calendar—this being the time at which the first new snow of the oncoming winter makes its appearance—all tend to show that the mean temperature must be fairly near what Lowell's theoretic deductions makes it.

Thus, this is the proof we have of the existence on *Mars* of the essentials to organic life—water vapor, oxygen, and sufficient warmth. In fact, nothing that we know of on our Earth explains the ever-changing polar caps of *Mars* except cloud and snow; nothing explains the existence of temporary clouding in its atmosphere, which occasionally veils large areas of its surface, but visible water vapor; and, lastly, the changes in the canals and other dark markings, as shown in the photographs, require vegetation for their satisfactory explanation. Then, it should appear that there is broad foundation in the observed facts for believing that vegetable life exists on the planet *Mars*.

As to animal life on the planet, I may say that this question really lies without our domain, but that the biologist, I believe, has not found the separate existence of plants or animals at any epoch in the evolution history of the Earth as shown by the fossil remains. And from our present day knowledge of the lowest forms of plant and animal life, it appears that the question of the ultimate separation of the two forms seems essentially insoluble. That is, plant and animal life come from the same original stock. From these facts we should expect the coeval existence of them on a planet and if, as it appears is the case, *Mars* possesses plant life then we cannot, it seems, logically exclude animal life.

Every observation agrees with this conclusion and, moreover, I can find no warranty in believing in a conclusion which is inconsistent with the observed facts.